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Development of Basic Data and Knowledge Regarding Organic Removal Capabilities of Commercially Available Home Water Treatment Units Utilizing Activated Carbon: Phase 1 Preliminary Report

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DEVELOPMENT OF BASIC DATA AND KNOWLEDGE REGARDING ORGANIC REMOVAL CAPABILITIES OF COMMERCIALLY AVAILABLE HOME WATER TREATMENT UNITS UTILIZING ACTIVATED CARBON

Preliminary Report - Phase 1

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This is the Phase 1 main report. Frank Bell, Project Officer.

16. ABSTRACT

An extensive study of commercially available home water treatment units has been conducted over a 3-year period to examine organics reduction and microbiological factors.

Phase 1 addressed trial protocol development and pilot testing using spiked and unspiked New Orleans tap water (6 units on each test). Before and after filter tests were run for trihalomethanes (THMs), non-purgeable total organic carbon (NPTOC), standard plate count (SPC) bacteria, endotoxin, silver levels (when appropriate), chlorine residuals and peripheral tests. Based on the pilot tests, unspiked tap water was selected as the main means of testing.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

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FOREWORD

In response to public concern with respect to interim measures for controlling organics in drinking water by the individual homeowner, EPA has contracted with GSRI to develop basic data and information on the performance of a variety of small home treatment units with respect to organics removal and bacterial/endotoxin aspects. The following report represents initial findings on seven units challenged with tap water and also tap water spiked with an additional 200 parts per billion (ppb) of chloroform to simulate more extreme conditions that are found in some drinking waters.

The principal purpose of Phase 1 was to develop data and information on a limited number of treatment units to provide guidance on the test procedures for use in the larger scale testing to be conducted in Phase 2. The relationship of the performance of the units tested in Phase 1 to other units, as yet untested, of course cannot be established until completion of the testing of the remaining units.

The Water Quality Improvement Standards and Certification Council (WQISCC), an organization representing water filter manufacturers, has reviewed and consulted on the project as it has proceeded. WQISCC has requested that it be made clear that many, if not most, of the test units have not been designed to remove the trihalomethanes and other organic chemical or microbiological parameters being measured. Most of the activated carbon home water treatment units have been designed to remove taste and odor only. In this study, many are being tested beyond their claims because consumers and responsible government bodies have a need to know their efficacy for organics removal.

Phases 2 and 3 of this contract, to be completed by the spring of 1980, will cover the testing of some 30 additional units, including an

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ozonator, 2 distillers, and 2 reverse osmosis units. Investigations at five field locations (Miami, Florida; Cincinnati, Ohio; Detroit, Michigan; Atlanta, Georgia, and Pico Rivera, California) and at three home installations will be completed and described in future reports.

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Project Officer
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CONTENTS

Foreword.....iii
Figures.....vi
Tables.....vii
Acknowledgment.....viii

1. Introduction..... 1
2. Program Objectives..... 3
3. Summary of Preliminary Results..... 4
   Further Studies..... 7
4. Experimental Procedures..... 9
   Test Protocols..... 9
   Selection of Units..... 16
   Analytical Method Verification and Quality Control..... 17
5. Results and Discussion..... 29
   General Observations..... 29
   Removal of Organic Contaminants by Home Treatment Units Using Activated Carbon..... 33

References..... 51

FIGURES

Number		Page
1	General usage profile indicating target sampling events	10
2	Routine daily schedule for all test models	13
3	Representative chromatogram of a check standard	19
4	Influent plate count and free chlorine concentrations	32
5	Summary performance of carbon units for THM removal	37
6	Summary performance of carbon units for NPTOC removal	40

TABLES

Number		Page
1	Chemical Characterization of Ambient New Orleans Test Water, July 1978	30
2	Physical Description of Study Carbon Models	34
3	Summary Performance-Trihalomethane Removal During Rated Lifetime	36
4	Summary Performance-Nonpurgeable Total Organic Carbon Removal During Rated Lifetime	39
5	Summary Performance of Activated Carbon Units for Removal of Nonpurgeable Total Organic Halides	42
6	Summary of Standard Plate Count Data	45
7	Summary of Endotoxin Data	48

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SECTION 1

INTRODUCTION

The primary goal of the program is to define selected performance characteristics of home treatment units for the information of consumers and Government agencies. Concern over trace contaminants in drinking water has been increasing over the past several years, and many manufacturers offer treatment units to the home market which may be of assistance in reducing concentrations of these trace contaminants. Various technologies, including activated carbon, reverse osmosis, distillation, and ozonation, are incorporated in these units. Activated carbon is used in the majority of applications due to its ability to remove taste and odor components and its relative economy.

Organic contaminants have been divided into five classes in the "Interim Treatment Guide for Controlling Organic Contaminants in Drinking Water Using Granular Activated Carbon" (1).

Class I Organic compounds that produce taste and odor.

Class II Synthetic organic compounds that are present in source wastes from upstream.

Class III Organic chemicals (precursors) that react with disinfectants to produce "disinfection by-products."

Class IV Organic chemicals that are the "disinfection by-products."

Class V Natural organic compounds.

Symons (1) summarized the literature in relation to the reported performance of activated carbon. This summary indicates 1. that compounds producing taste and odor are well removed by activated carbon; 2. that adsorption of synthetic organic compounds is variable (some of these compounds, such as pesticides and polynuclear aromatics, are

strongly adsorbed, while others such as carbon tetrachloride are not); and 3. that the disinfection by-products, both precursors and trihalomethanes, are adsorbed at a much lower capacity than pesticides and taste- and odor-causing compounds.

Of the five classes of compounds, synthetic organics and disinfection by-products (precursors) have been identified as potential health hazards. Activated carbon, when properly applied, can usually reduce the presence of these compounds. It has been shown that the environment within some activated carbon units is conducive to rapid bacterial growth (2,3). In an effort to control this growth, many manufacturers incorporate silver in a complex reduced salt form within the activated carbon units. The silver salt is believed to be released at a rate sufficient to suspend bacterial growth without exceeding maximum contaminant levels for silver. Units of this type must be registered by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act.

The evaluation program for this project is divided into three phases. During Phase 1, seven different models having a range of capacities, flow rates, and recommended plumbing configurations were evaluated at two stress levels. Experience gained from Phase 1 testing has been used to plan a protocol for the operation and evaluation of units in the remaining two phases. Phase 2 will involve testing approximately 30 additional units using protocols similar to those used in Phase 1. Phase 3 will include evaluation of non-carbon units; more detailed evaluations of selected carbon units; field studies on selected units in five cities (Miami, Florida; Atlanta, Georgia; Detroit, Michigan; Cincinnati, Ohio, and Pico Rivera, California); and stress studies on selected units involving additional organic chemical spikes. This report covers the results of the Phase 1 evaluation. To reduce the bulk of the report, most of the basic data and plots of results for individual units have been included in "Phase 1 Supplemental Data," which is available on request.

SECTION 2

PROGRAM OBJECTIVES

The purposes of this study are to develop data and information for the guidance of interested consumers and Government agencies and to develop basic scientific information on the performance of small home water treatment units. The results of these studies may form a basis to encourage further development of small home treatment units to provide water of improved quality to the user.

SECTION 3

SUMMARY OF PRELIMINARY RESULTS

Gulf South Research Institute has evaluated seven activated carbon home water treatment units for removal capabilities with respect to broad-scale organic materials (nonpurgeable total organic carbon, NPTOC), trihalomethanes (THM), and other halogenated compounds (nonpurgeable total organic halogen, NPTOHa). Evaluation of bacterial and endotoxin content was included in the study. The protocol for testing was developed jointly with EPA and was reviewed by a representative committee of the Water Quality Improvement Standards and Certification Council. Some of the unit manufacturers have not made explicit claims for organics removal, and only three have made claims for bacteriostatic effects; consequently, some units may have been tested beyond their claims to provide the needed information for the guidance of consumers and Government. The units were generally operated according to the manufacturer's instructions where such were reasonable and likely to be followed by consumers. The philosophy of the test program was to stress the units under simulated home use. All units were challenged with New Orleans tap water, the first six with ambient water. Five of the same units plus one new unit were evaluated with ambient water spiked by 200 ppb of chloroform to simulate conditions that have been found in some water supplies.

The seven units in Phase 1 of the study were selected to reflect a variety of activated carbon applications including two faucet filters (one bypass and one non-bypass), one portable pour-through filter, one stationary filter, and three line bypass filters. Three incorporated silver-impregnated activated carbon and four were non-silver units. Since one faucet filter showed negligible removal capabilities for THM and NPTOC in the tap water test, it was replaced in the spiked water test by a line bypass filter model.

In general, these filters consist of units containing various amounts of granular activated carbon (16 to 1120 g). They were installed to allow flow rates simulating flow from the home tap and result in contact periods ranging from 0.5 to 46 seconds. By comparison, large scale central water treatment granular activated carbon filters range from 2 to 15 feet deep and contact periods range from 5 to 30 minutes.

Preliminary results under conditions of these tests are summarized below.

1. THM: Small faucet and pour-through filters removed amounts ranging from negligible to about one-quarter of the influent THM during the manufacturer's recommended filter life. Larger stationary and line bypass filters removed greater percentages, ranging from 43-46 percent to over 90 percent for one filter. The extent of THM removal appears to be a function of several factors, including the quantity of carbon relative to treated water, contact time, and design factors.

2. Other Organic Parameters: Percent removal of nonpurgeable total organic carbon and nonpurgeable total organic halogen was lower than percent removal of THM for all units. Again, the larger filters showed higher removals than smaller units.

3. Bacterial Standard Plate Count (SPC): A majority of the effluent bacterial levels for 5 of the 7 units were within $\pm$ 1 log unit (10 times) of influent levels, with frequencies for individual units varying from 41 to 83 percent. The effluents of all filter units contained populatons which exceeded influent levels by more than 1 log unit, with frequencies ranging from 15 to 59 percent. However, rapid shifts/reversals in population numbers were also apparent on consecutive sampling periods. Effluent levels were one-tenth or less than influent levels at some periods for 3 units, with frequencies ranging from 8 to 18 percent. None of the silver-impregnated units consistently demonstrated bacteriostatic properties in these preliminary tests. Background tests were run for coliform bacteria; none was found.

4. Endotoxin: Most of the effluent endotoxin levels were within a range from one-half to double influent concentrations, with frequencies for individual units ranging from 50 to 69 percent. The effluents of all filter units contained double the influent levels at frequencies varying from 33 to 46 percent for individual units. However, rapid shifts/

reversals in endotoxin levels were also apparent on consecutive sampling periods. Effluent levels were one-half or less than influent levels for 4 units with frequencies ranging from 1 to 10 percent. There appeared to be no discernible difference between silver and non-silver units with respect to endotoxin levels.

The following observations have been developed in review.

1. THM: Trihalomethanes comprise chloroform and other halogenated methanes produced in large quantities during the chlorine disinfection of drinking water supplies and are the subject of a suggested maximum contaminant level (MCL) of 0.10 mg/l in EPA's proposed organic chemical control regulations. These preliminary results showed that during the recommended life of the units, THM removal for faucet and pour-through filters ranged from negligible to 25 percent of influent THM. Three stationary and line bypass filters removed from 43 to 46 percent; one unit removed more than 90 percent.

2. Other Organic Parameters: NPTOC represents the bulk of organic compounds in drinking water, believed to be mostly natural materials of high molecular weight. NPTOC analyses were included to provide background information, and the results showed removal capabilities ranging fr.. 2 to 41 percent by the units. Some of these materials are precursors to the formation of THMs and other chemicals.

NPTOHa represents the nonvolatile chlorinated and other halogenated organic compounds, which are produced primarily in the disinfection process, although some may be present in the raw source water. The NPTOHa analyses were conducted by the Kuhn-Dressman technique; limited data showed variable removals, including negative values. Average removal was not computed for most units, but one unit removed 79 percent NPTOHa.

3. Bacteria: There is evidence in the literature that bacteria can colonize and multiply on activated carbon and other surfaces; further, that bacteria can multiply in tap water once residual chlorine has dissipated. Since the units being tested were primarily intended for the consumer who uses disinfected water from a public water supply, removal or growth of pathogenic bacteria was not investigated.

Principal focus of the bacterial study was the standard plate count procedure, which defines bacteria nearly always present in tap water and

considered to be nonpathogenic under normal situations. Major interests of the study were the effects of carbon filters and silver impregnation on bacterial numbers. With the carbon filters, effluent SPC sometimes exceeded influent levels at one sampling point, while concentrations at the next point were lower than influent levels; in general, carbon filters seemed to have moderate and variable effects on bacteria levels. Silver impregnation appeared to have some impact on bacterial levels but was not judged consistently bacteriostatic for the units tested.

4. Endotoxin: By far the largest portion (the Gram-negative bacteria) of bacteria in drinking water release endotoxins from their cell walls upon their death. Thus, in theory, higher SPC may be associated with higher levels of endotoxin in drinking water. When injected into the blood stream of animals or humans, endotoxins can elevate body temperatures. However, endotoxins in water are introduced to the gastrointestinal tract rather than directly into the blood, at very low concentrations. While endotoxins are presently not known to be a hazard in drinking water, they are still of interest as representing bacterial activity.

While the results showed some increases in effluent endotoxin levels over the influent levels, maximum effluent levels (6.6 to 18.0 ng/ml) were comparable to maximum levels found in public water supplies as reported by one EPA contractor (4). Reversals also occurred in the relative influent-effluent levels, and the results must be considered variable. Data were too limited to correlate SPC and endotoxin levels. Silver-impregnated filters showed little, if any differences in their pattern of endotoxin levels as compared to non-silver filters.

FURTHER STUDIES

This preliminary report represents the results of tests on 7 different water treatment units available for home use. Further laboratory studies will include about 30 additional activated carbon filters, 2 reverse osmosis units, 2 distillers, and 1 ozonator; proposed spiking studies will assist to understand removal capabilities for a variety of other organic chemicals; finally, home use and field studies will contribute to a better understanding

of removal capabilities for the organic chemicals and bacterial and endotoxin aspects for home water treatment units.

SECTION 4

EXPERIMENTAL PROCEDURES

TEST PROTOCOLS

Overview of Phase 1

Phase 1 evaluations consisted of three test runs for each model at each of two levels of chloroform challenge. Seven models were evaluated. The first three runs on six of the models used ambient water from the GSRI laboratory as a challenge; the remaining three runs on five of the same models plus one new model were performed using ambient water spiked with chloroform to an elevated trihalomethane level. One of the faucet models removed only negligible amounts of THMS and NPTOC; this unit was replaced in the spiked water tests. The chloroform concentration was elevated by approximately 200 ppb. By using two THM levels, performance characteristics were determined under two different levels of stress.

Performance parameters monitored were nonpurgeable total organic carbon, trihalomethanes, free and total chlorine, nonpurgeable total organic halide, standard plate count, and endotoxin. NPTOC and THM analyses were performed at least five times during the life of the test units. These five events corresponded to approximately 0, 25, 50, 75, and 100 percent of the total unit life expectancy, as claimed by the manufacturer or assigned in lieu of a practical claim (an indefinite life was claimed for one unit). Figure 1 depicts a general usage profile showing the main sampling events for the duplicate and triplicate tests of each model. NPTOHa analyses were conducted on a more limited basis to obtain indications of removal capabilities for this broad scale halogenated organic parameter. Basic analyses performed on the treated water are indicated. Silver analysis was done only on the waters from models incorporating silver in the carbon matrix.

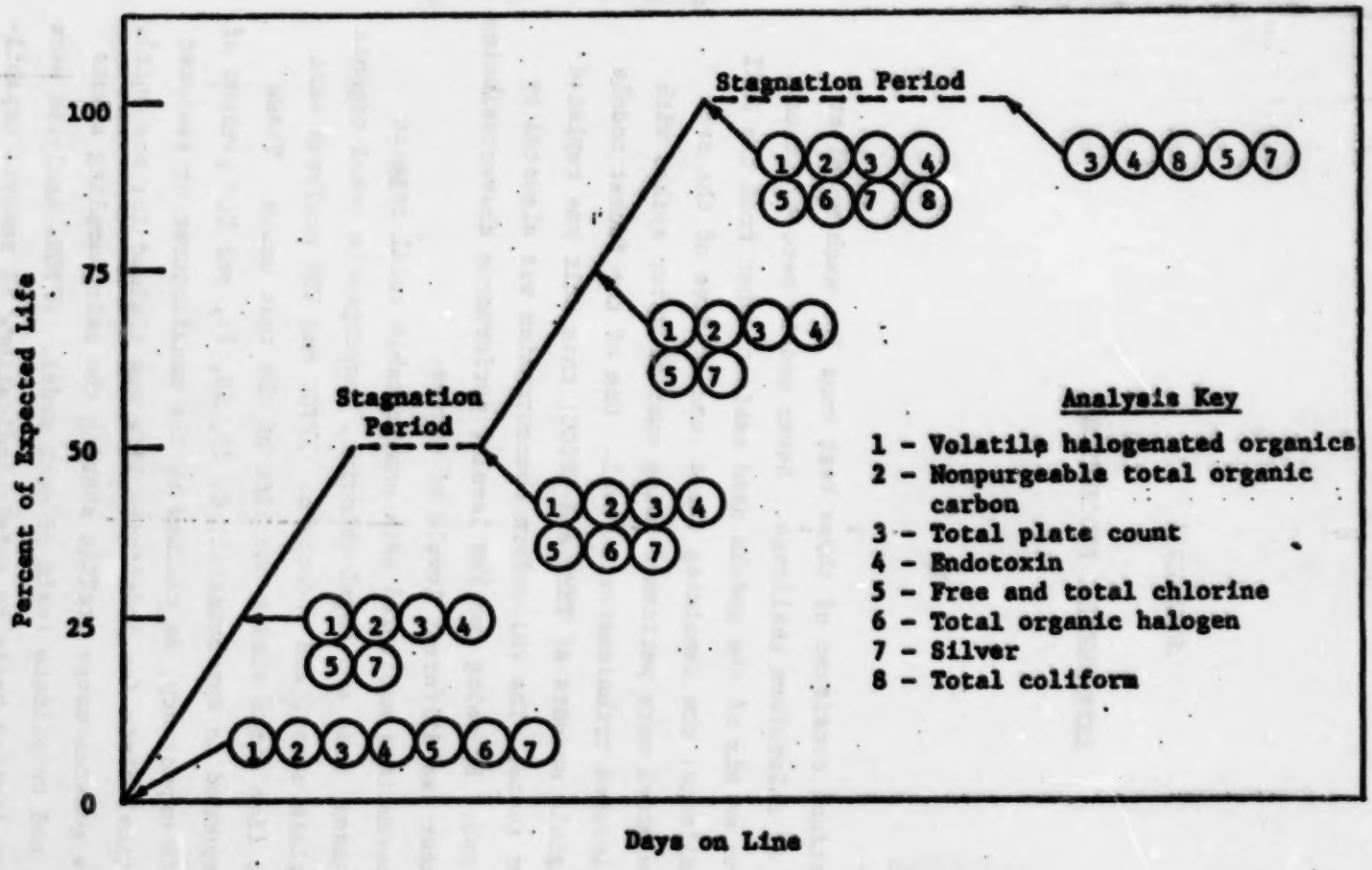

Figure 1. General usage profile indicating target sampling events.

Standard plate count and endotoxin analyses were performed on influent and effluent samples collected at least five times during each of two runs on each test model. These analyses were performed using standard methods. Sampling events for units having long runs were spaced evenly over the duration of the run.

Chlorine analyses were performed on influent and effluent waters from the test units whenever THM/NPTOC or SPC/endotoxin samples were collected. The chlorine and silver in samples collected for SPC/endotoxin analysis were inactivated with a sodium thiosulfate/sodium thioglycolate mixture and the samples were stored at 4°C until analyzed. Chlorine in samples collected for THM/NPTOC analysis was neutralized with sodium sulfite. These neutralizing solutions are generally accepted as adequate to quench the haloform reaction and neutralize the bacteriostatic effect of silver and chlorine.

These procedures were designed to yield accurate, reliable data to evaluate the effectiveness of the units in reduction or removal of trihalomethanes and nonpurgeable total organic carbon and to provide important information on bacterial and endotoxin content. The protocols were developed following the suggested standards of the WQISCC and incorporated input from EPA, private manufacturers, and industry.

Scheduling

A tentative schedule for sampling events and run duration was established based on unit capacities and flow rates. The unit flow rate is determined by water pressure and the pressure drop across the complete filter assembly. In some cases the pressure drop is determined, at least initially, by one or more restrictive orifices either within the unit or in the associated plumbing. Sampling events were scheduled at or near predetermined gallonage values for each model.

Recommended gallonage values are critical for scheduling since in conjunction with flow rates and running times the total gallonage determines the maximum duration of the run and spacing of sampling events. For units where flow rates and gallonages were not available, values for similar units with equivalent amounts of carbon were used. By this means the total number of gallons to be processed by each unit per day was estab-

lished. Three runs were performed for each test model for each type of challenge water. The first run was a "range-finding run" during which the total rated gallonage was confirmed. The run was designed to be as short as possible, with the total run not to be less than five days. The maximum flow time available to any unit was set by the timer cam control system to approximately 466 minutes per day. This provided approximately 29 minutes of running time for each of the 16 daily cycles. During the second and third runs for each model, the target duty cycle was limited to no more than 10 percent "on" for each hour during the 16 hour working day. Therefore, for each of the 16 hours of manifold operation each day, the running time was limited to approximately 6 minutes per cycle, or 96 minutes a day.

A typical 24-hour day is depicted in Figure 2. Each day included an 8-hour stagnation which simulated overnight non-usage time; most bacterial/endotoxin samples were collected immediately after the stagnation period. The units were then run for 16 hours, held stagnant for 8 hours, and the cycle was repeated. Both influent and effluent waters from the units were analyzed for standard plate count and endotoxin during the second and third runs for each of the test models. The samples were collected as "first waters" off the treatment units in the morning. At least five effluent samples were collected over the life (rated gallonage) of the unit. In addition to the "first water" samples, several "running water" samples were collected for SPC/endotoxin analysis.

A five-event sampling schedule for analysis of effluent waters from each of the test units was established for THM and NPTOC. Samples were collected approximately six hours after the start of the test day and one minute after the downstream holdup volume of the unit had been wasted. This ensured collection of a dynamic sample rather than a sample which had extended contact time with the adsorbent material. Several samples were collected after instituting a decelerated test pattern typical of average home usage. The first five cycles of the test day were conducted at the decelerated pattern. Samples were collected during the sixth cycle and the results were compared to sample data from the normal test pattern on a duplicate test run to assure that temporal effects were found.

The units were run until the manufacturer's rated gallonage had been processed or until the unit failed by premature plugging. While early protocols included a chemical failure point (10 percent or less removal),

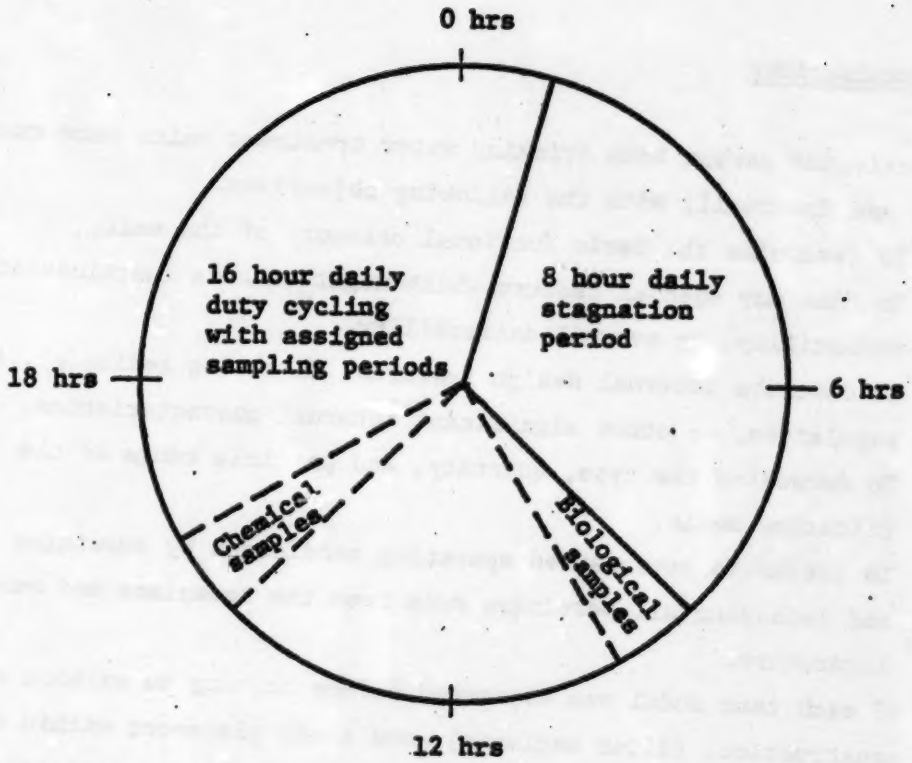

Figure 2. Routine daily schedule for all test models.

this was never implemented. The faucet unit advertized as having an "indefinite lifetime" was assigned a lifetime of 200 gallons for this test. A bacterial sample was collected five days after the termination of a run to determine what effect an extended dormancy period had upon effluent water quality. When a run was complete, the flow through the unit was stopped and the unit was held under line pressure, if applicable, for five days; at this time the unit was turned on long enough to collect the last SPC/endotoxin sample.

Physical Examinations

The activated carbon home drinking water treatment units were examined externally and internally with the following objectives.

1. To determine the basic fuctional category of the unit.
2. To find any special feature which might enhance functionality, versatility, or overall desirability.
3. To describe internal design features, filtering medium(s), flow regulators, or other significant internal characteristics.
4. To determine the type, quantity, and particle range of the filtering media.
5. To establish recommended operating conditions by examining and recording all pertinent data from the nameplate and enclosed literature.

One of each test model was dissected before testing to examine the internal construction, filter medium(s), and their placement within the unit. Samples of the carbon were collected aseptically for evaluation of bacterial and endotoxin content and determination of iodine numbers (6). Filter media were classified by type (sand, carbon, zeolite, etc.) and gross shape (powder, granular, or pellet). The granular carbon was sieved to determine the size and distribution of particles. The total weight of carbon was used to estimate total unit capacity on units not rated for this parameter. The apparent internal flow design of the unit was recorded.

Performance Testing

In the first phase of the project, five major parameters were monitored: volatile halogenated organics, nonpurgeable total organic carbon, nonpurgeable total organic halides, standard plate count, and endotoxin. Other complementary data, including total gallonage, water temperature, free and total chlorine of influent and effluent waters, and time and date of sampling, were recorded. Limited coliform data, iodine numbers, total organic halogen levels, as well as influent and effluent silver concentrations, were determined for those units with silver. One set of samples was analyzed by gas chromatography/mass spectrometry for broad scale organic removal.

The THM analysis is one of the most important measures of performance since trihalomethanes result from the chlorine disinfection process and therefore are present in all chlorinated drinking waters. THMs are covered in EPA's proposed organic chemical regulations. Carbon units may remove THM concentrations in tap water, and definite experimental information on their capabilities is needed.

Standard plate counts are also expected to yield important data. Since the water to be filtered by most of these units is not contaminated with pathogenic bacteria, the units are not used to sanitize the water. However, data have been published (2,3,7) which indicate that many activated carbons and other surfaces support general bacterial growth. The scheduled standard plate count analyses provide an evaluation of the bacterial quality of effluents from these units as compared to influents.

In an effort to control the potential bacterial growths on activated carbon surfaces, some manufacturers have impregnated the carbon with complex, slow-dissolving silver salts which act bacteriostatically. However, when bacteria die, endotoxins are released. Although limited research has been done to determine endotoxin levels in drinking water almost no work has been done to determine endotoxin levels in activated carbon units. The other data collected will help broaden the understanding of the adsorption process and may help explain trends in the data developed by observing the above parameters.

Each unit was installed on the test manifold and was plumbed according to the manufacturer's recommendations. Suggested startup procedures were

completed before the run was started. Duty cycles were set according to the described schedule. Flow through most units is not usually regulated except by restrictions in the plumbing, primarily the faucet and line tapping valves. The test manifold was designed with oversized tubing so that the manifold itself was not flow restricting. The test flow rates were determined by evaluating the flow through the plumbing train (including an appropriate faucet and tapping valves) with the variable orifice monitor/controller fully open. The pressure was held constant at 40 psi. The faucet was then removed from the plumbing train and the unit installed. If the flow rate exceeded that originally allowed by the manufacturer-supplied hardware, the controller was set to the flow rate determined in the original test. Through this initial adjustment, the normal maximum flow rate was applied to each model during each run. The same procedure was followed for all units operating in the pressurized mode. An exception was made for one faucet unit which was operated at the manufacturer's recommended flow rate for the ambient tap water tests but as indicated above for the spiked water tests. Flow through the pour-through units was set to the manufacturer's recommended values by adjustment of the variable orifice controller.

SELECTION OF UNITS

The water treatment devices selected for study were chosen on the basis of the following criteria:

1. Size-models were selected to cover a range of sizes but limited to devices small enough to be conveniently utilized in most domestic kitchens.
2. Installation configuration-the models selected for Phase 1 study were grouped into one of four categories depending upon intended plumbing configuration or principal treatment process. The categories were pour-through, faucet attached, stationary, and line bypass. Within each category, study models were selected to cover a range of sizes, capacities, filtration media, etc.
3. Claims-some selections were based upon special claims or unique features (e.g., chloroform removal, automatic flow control,

bacteriostatic capabilities). Specific organic removal claims received special attention since these claims could be validated through the test protocol.

4. Availability. The units for study in Phase 1 were selected as examples of the gamut of activated carbon filters:

   a. Faucet filters
      1. Instapure Model F1-C (bypass)
      2. Mini Aqua Filter (no-bypass, tap water test only)
   b. Stationary
      1. Sears Taste and Odor Filter
   c. Pour-through
      1. H_2OK* Portable Drinking Water Treatment Unit
   d. Line bypass
      1. System 1* Water Processor, Model SY1-34
      2. Aqualux* Water Processor, Model HB
      3. Everpure (added to the Phase 1 study for the spiked water test): Model QC4-THM

*Incorporate silver-impregnated carbon.

ANALYTICAL METHOD VERIFICATION AND QUALITY CONTROL

Volatile Halogenated Organics Analysis

Sampling--

Cleaning and sampling techniques used in collecting the samples to be analyzed for volatile halogenated organic compounds are described below. (Crimp-top serum bottles with Teflon-lined septa are used.)

--Wash in a hot soap and water solution.
--Rinse in tap water.
--Rinse in Chromerge.
-Rinse thoroughly in deionized water.
--Rinse thoroughly in distilled water.
--Rinse in methanol.
--Drain dry.
--Rinse in pentane.

—Blow dry with a stream of ultrahigh purity (UHP) nitrogen.

—Heat at 400°C for at least 1 hour.

—Cool to room temperature.

—Add 1 ml of 0.25 percent sodium sulfite per 100 ml sample.

—Cap using Teflon septum and crimp top, making sure the Teflon lining faces the sample.

When samples are collected, the crimp top is removed and the bottle is filled to overflowing. Care is taken in resealing the sample bottle to avoid inclusion of air in the bottle because air pockets could result in the loss of volatile organic compounds. Samples are refrigerated at 4°C until analysis.

Analysis—

The THM analysis of water samples is carried out using liquid-liquid extraction techniques followed by separation and determination of the four compounds of interest by gas chromatography (GC) with a ^{63}Ni electron capture (EC) detector (8). This method has been shown to produce results which correlate well with those generated by purge-and-trap procedures (9).

Reagent grade methylcyclohexane (MCH) is used as the extracting solvent. MCH is purified by distillation and, if necessary, by passing it through a basic alumina column. A 5 ml aliquot of sample is extracted by shaking with 1 ml purified MCH. The layers are allowed to separate, an aliquot of the organic layer is drawn off, and a 3 µl portion is injected into the GC. Chromatographic conditions for this analysis are presented in the supplementary data report, Table S1. Figure 3 shows a typical chromatogram of a drinking water sample. Qualitative identification is based on matching the retention times of the peaks in the sample chromatogram with those in the chromatogram of a standard containing the four compounds of interest: chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Comfirmation is obtained by reanalyzing any sample in question under different conditions of liquid phase, solid support, temperature, and flow rate (Table S1) and comparing the retention times of peaks in the sample chromatogram with those of a standard analyzed under these same conditions. The quantification technique used is the external standards method, and all calculations are based on integrated peak areas.

LEGEND

Peak	Compound	Concentration (ppb)
1	Chloroform	179
2	Bromodichloromethane	23.8
3	Chlorodibromomethane	4.4
4	Bromoform	6.5

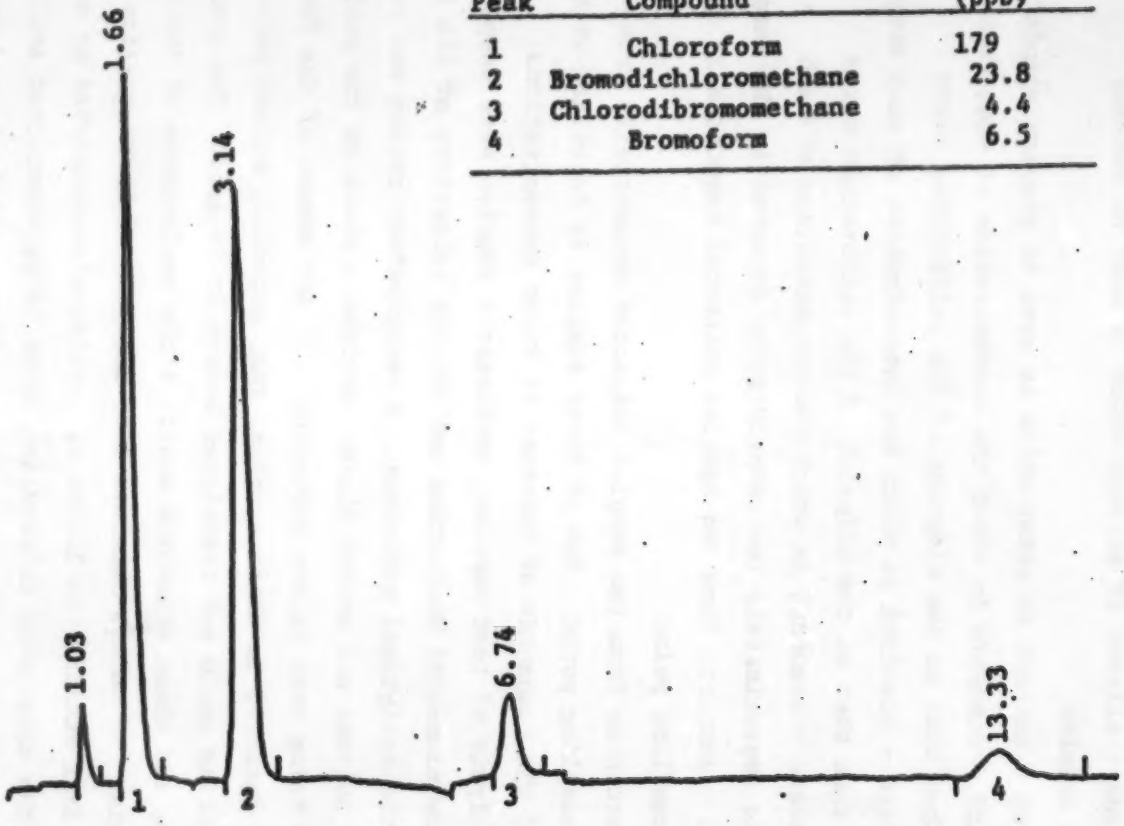

Figure 3. Representative Chromatogram of a Check Standard

Quality Control—

A rigorous quality control program is being followed in conjunction with the THM analysis. A nine-point calibration curve was constructed for each compound. The following quality control samples are run daily.

—solvent blank - aliquot of solvent which is used to extract that day's samples

—method blank - extract of water which is used to prepare standard

—low standard - standard in which the concentration of each compound is lower than that at the midpoint of the calibration curve

—high standard - standard in which the concentration of each compound is higher than that at the midpoint of the calibration curve

—check standard - standard in which the concentration of each compound is approximately the concentration expected in the samples

—duplicates - extracts from two samples collected sequentially from the same sampling point

—spikes - extracts from two samples collected sequentially from the same sampling point. One of these samples is fortified with a mixture of the compounds of interest at known concentrations.

Prior to analysis of test samples, performance samples were supplied to GSRI by the Environmental Monitoring and Support Laboratory of EPA for verification of the analytical procedure. A satisfactory rating was received.

Analysis of solvent and method blanks provides a check on the purity of the materials being used in the procedure. If any amount of the four THM compounds is detected in these samples, that material, either solvent or water, is purified again and reanalyzed before it is used. The analysis of the low, high, and check standards monitors the performance of the GC on a day-to-day basis. If values obtained from analysis of these quality control samples fall outside the limits of precision (established by analysis of duplicates), the nine-point calibration curve is reconstructed and/or a thorough check of the instrument parameters, column conditions, and detector response is made.

The precision of the procedure is established by the analysis of duplicates. Precision is quantified according to the equation

$$R_c = 3.27\ C \frac{\Sigma R_i}{\Sigma X_i} \qquad (1)$$

where

R_c = critical difference
X_i = average value obtained for duplicate analyses
R_i = difference between the values obtained for duplicate analyses.

Qualitatively, the smaller the R_c value, the better the precision of the analysis. Quality control charts are generated from these data and are updated every day THM analyses are performed.

Accuracy of the THM analyses is monitored by comparing the value obtained for the check standard with the actual value. The recovery efficiency of the analysis is determined by analyzing spiked samples and comparing the difference in the values obtained for the spikad and unspiked samples with the level at which the sample is spiked. Generally, if the THM concentration in the sample is expected to fall in the lower half of the calibration curve, the sample is spiked at a level approximately equal to the concentration of the compounds already present. If the sample concentration is anticipated to be above that of the midway point of the calibration curve, the spike is approximately half of the value expected in the sample. Quality assurance data are presented in detail in "Phase 1 Supplemental Data," Tables S2 through S4.

Nonpurgeable Total Organic Carbon Analysis

Sampling--

Cleaning and sampling techniques used in collecting samples for nonpurgeable total organic carbon analysis are identical to those used in the VHO analysis procedure.

Analysis--

NPTOC analyses are performed using the Dohrmann model 54 analyzer. Using this procedure, 10 ml of sample is presented to the instrument, acidified, purged for inorganic carbon, and oxidized using an ultraviolet catalyzed system. The carbon dioxide produced is converted to methane, and the methane is detected using a flame ionization detector.

Quality Control--

The quality control program associated with the NPTOC analyses contains the same elements described for the VHO analyses, including satisfactory performance on an EPA quality control sample. During the first half of Phase 1, all quality control samples (i.e., water blank, method blank, low standard, high standard, check standard, duplicates, and spikes) were analyzed daily. Because NPTOC analysis is fairly time consuming (20 min per sample), this level of quality control constituted approximately 40 to 50 percent of the labor effort. Quality control data generated during this period demonstrated that this method for the analysis of NPTOC is very reliable. Therefore, at the suggestion of the project officer, Mr. Frank Bell, during the second half of Phase 1 the number of quality control samples analyzed in conjunction with the NPTOC procedure was reduced. During this period, the schedule for the analysis of quality control samples was as follows.

Monday - water blank, method blank, low standard, high standard, check standard, duplicates, and spikes

Tuesday and Thursday - water blank, method blank, low standard, check standard, and duplicates

Wednesday and Friday - water blank, method blank, high standard, check standard, and spikes.

Precision, accuracy, and recovery data for the NPTOC analyses are included in the supplementary data, Tables S5, through S7.

Nonpurgeable Total Organic Halogen Analysis

Sampling--

Preparation of glassware for collection of samples for nonpurgeable total organic halogen (NPTOHa) analysis follows the sample procedures

outlined for VHO samples. For NPTOHa analysis, 10 liters of sample is collected and stored in three 1-gallon jugs at 4°C. Sodium sulfite (1 ml of 0.25 percent solution per 100 ml of sample) is used to quench the free chlorine, but no attempt is made to eliminate headspace from the bottles.

Analysis--

NPTOHa analysis is carried out using a procedure developed by Kühn (10) and modified by Dressman (11). An outline of this method is presented below.

1) The water sample (10 liters) is purged with UHP nitrogen for 75 min at a flow rate of 5 liters per minute.
2) Ten liters of water, to which has been added 685 mg of sodium nitrate per liter of sample, is extracted for 1 hr with 1 g of granular activated carbon previously powdered 90 sec in a laboratory mill, and wetted with Super-Q water for 30 min under vacuum. The sample is stirred at 200-500 rpm.
3) The carbon is settled by adding 50 ml of aluminum sulfate solution (1 g of aluminum/liter) and sufficient 5N sodium hydroxide to maintain pH in the range of 6.5 to 7.5, and then 20 ml of polyacrylamide floc aid (200 mg/l) is added. The stirring rate is reduced below 100 rpm during floc formation (about 10 min).
4) The sample is allowed to stand until floc has settled completely. (Time required depends on the nature of the sample. A period from 30 min to overnight is required.) The supernatant liquor is siphoned off to leave behind about 200 ml with the sludge. The sludge is quantitatively transferred to a beaker. The supernatant liquor is returned to the extraction vessel and steps 2 through 4 are repeated.
5) The sludge in the beaker is allowed to settle for 5 or 10 min. The supernatant liquor is poured from the beaker through 9-μm pore diameter cellulose acetate filter and the sludge washed onto filter paper for vacuum filtration. The filtered sludge cake is returned to the same beaker, now containing 200 ml of 685 mg/l sodium nitrate (500 mg/l NO_3^-) wash solution, by washing the sludge from the filter membrane with a small amount of Super-Q

water. A stirring bar is added and the sample is stirred moderately for 1 hr on a stir jack. The sludge is settled and refiltered as before. Step 5 is repeated on the sludge recovered from the second extraction.

6) The sludge cakes from the filter membranes are combined into a quartz boat and pyrohydrolyzed at 700°C.

7) The pyrohydrolyzate is collected and the halide content is determined by coulometric titration using a Dohrmann model C-300 microcoulometer and T-300-S titration cell.

Quality Control—

This procedure for the analysis of TOHa is very time consuming. The elapsed time from the beginning of the sample purge to the generation of final data is approximately 30 hr. Because of this, quality control samples (blanks, standards, duplicates, and spikes) were analyzed only every 20 samples. Precision, accuracy, and recovery data are included in "Phase 1 Supplemental Data," Tables S8 through S10.

Gas Chromatographic/Mass Spectrometric Analysis

Sampling—

The procedures used to prepare glassware and collect samples for volatile organic analysis (VOA) and semivolatile analysis (SVA) by gas chromatography/mass spectrometry (GC/MS) are the same as for THM samples. For GC/MS analysis a volume of approximately 25 ml for VOA and 4 liters for SVA was collected and stored at 4°C in glass bottles equipped with Teflon-lined screw tops.

Analysis—

The procedure used to prepare and analyze (identify and quantify each compound) each sample for volatile, or purgeable, organic compounds was a modification of the purge-and-trap technique developed by Bellar and Lichtenberg (12). Semivolatile analyses were performed using procedures commonly employed in priority pollutant analysis (13).

Instrumentation used in the analysis of volatile compounds included a Hewlett-Packard model 5710 gas chromatograph equipped with a all glass capillary injector system. This GC was interfaced with a Hewlett-Packard model 5982 mass spectrometer equipped with a dual electron ionization/chemical ionization source. Data acquisition and manipulation were accomplished with a System Industries model 150 data system. Instrumentation used in the analysis of semivolatile organic compounds included a Hewlett-Packard model 5840 gas chromatograph interfaced with a Hewlett-Packard model 5985A mass spectrometer with dual electron ionization/chemical ionization sources. Data acquisition and manipulation were accomplished using a Hewlett-Packard model 21MX-E series data system.

Quality Assurance—

The GC/MS system was tuned daily using perfluorotributylamine (PFTBA) in accordance with manufacturer instructions. Instrument performance was verified by inspection of the mass spectrum of decafluorotriphenylphosphine (DFTPP), a compound which is sensitive to subtle changes in tuning characteristics of the mass spectrometer (14). Laboratory blanks were prepared and analyzed along with the samples. The presence of a compound was reported only if detected at a concentration greater than twice that in the blank.

Inorganic Analyses

Sampling—

Glass bottles are washed in hot water and detergent, rinsed well with tap water and deionized water, cleaned with 1:1 nitric acid, rinsed thoroughly with deionized water, and drained dry.

Samples for trace metal and nitrate analysis are preserved upon collection with concentrated nitric acid to lower the pH to less than 2 and are stored at 4°C. Samples to be analyzed for fluoride, residue, turbidity, and conductivity are preserved by cooling to 4°C. Samples on which pH is to be determined are analyzed immediately, and thus no preservation is necessary.

Analysis—

Influent and effluent samples to be analyzed for silver are prepared for analysis by digesting 200 ml of sample with 3 ml concentrated nitric acid and 5 ml 30% hydrogen peroxide. The samples are covered with a watch glass and heated at 95°C until the volume is reduced by evaporation to less than 50 ml. The digested sample is cooled and diluted to 50 ml with distilled, deionized water. The digested, concentrated samples are analyzed for silver using a Perkin-Elmer 303 or 306 atomic absorption spectrophotometer (AAS) equipped with a heated graphite atomizer (HGA 2000 or HGA 2100), deuterium background correction, and a chart recorder. A series of standards is prepared and analyzed with each set of samples. The height of the absorbance peak of each standard is measured and is used with the concentration of the standard for constructing a calibration plot. Samples are quantified by comparison of the absorbance peak height to the standard plot.

Arsenic, barium, cadmium, chromium, lead, and selenium are determined in a similar manner on an influent sample by flameless atomic absorption using a Perkin-Elmer 303 AAS equipped with a HGA 2000, deuterium background correction, and a chart recorder. Samples are prepared for analysis by digesting 100 ml of sample with 3 ml concentrated nitric acid and 5 ml 30% hydrogen peroxide (15). The following inorganic parameters are determined using techniques cited in the Manual of Methods for Chemical Analysis of Water and Wastewater (16). Fluoride is measured using an Orion ion activity electrode. The cadmium-reduction method is used to determine nitrate nitrogen. Total dissolved residue is determined gravimetrically. A nephelometer is used for determination of turbidity. Conductivity and pH are determined with a YSI conductivity bridge and an Orion digital pH meter.

Quality Control—

A quality control program is being conducted concurrently with the analytical program. A minimum of 10 percent of analyses run are to assure quality of the data generated. These quality assurance samples include duplicate samples, spiked samples, and quality control standards. Precision,

accuracy, and recovery data for silver analysis are presented in the supplementary data Tables S11, S12, and S13.

Microbiological Analysis

Sampling—

All sample bottles and glassware used for microbiological analyses are washed with detergent and hot water, rinsed with hot tap water, and thoroughly rinsed with distilled water. The glassware is sterilized by heating at 170°C for 60 minutes. A sterile filtered solution of 7.3% sodium thiosulfate and 5% sodium thioglycolate is added to each sample upon collection at the rate of 1 ml per 100 ml sample. The thiosulfate and thioglycolate neutralize any chlorine or silver present in the sample and thereby prevent bacterial kill after sample collection. Samples are cooled to 4° immediately and stored until analysis. Standard plate count and coliform analyses were performed according to standard procedures (17).

Analysis—

Standard Plate Count—A standard plate count is done within 30 hours of sample collection. Dehydrated standard plate count agar is reconstituted and sterilized according to the manufacturer's instructions. The agar is melted and tempered in a 44°-46°C water bath. Samples are diluted with sterile water and plated in duplicate at the following concentrations: influent 10^{-1}, 10^{-2}, 10^{-3}, effluent, 10^{-2}, 10^{-3}, 10^{-4}, and carbon, 10^{0}, 10^{-1}, 10^{-2}. The plates are incubated at 35° $\pm$ 0.5°C for 48 $\pm$ 3 hours, and colonies on each plate are counted with the aid of a Quebec colony counter. During the first part of Phase 1 some samples were held longer than 30 hours and not run in duplicate: these results have been examined and are felt to be valid. The remaining samples were analyzed in duplicate and analyzed within 30 hours after sampling as is specified in Standard Methods (17).

Standard Total Coliform—The standard total coliform membrane filter procedure was selected over the multiple-tube fermentation technique because of the opportunity it provides to examine large volumes of water,

generate highly reproducible data, and test a large number of samples with ease. One hundred milliliters of sample is passed through a 0.45 μ pore diameter membrane filter. The filter is placed on an M Endo medium saturated pad and incubated for 24 ± 2 hours at 35° ± 0.5°C. Colonies having a pink to dark-red color with a metallic sheen are assumed to be coliforms and are counted with the aid of a Quebec colony counter. In Phase 2 the identity of all colonies assumed to be coliforms will be confirmed by the multiple-tube fermentation procedure.

Endotoxin Assay—The endotoxin assay is conducted using the Worthington Limulus amebocyte lysate Pyrostat test kit, a turbidimetric modification of the Limulus amebocyte lysate gel test for detecting pyrogen. Each sample is diluted 1:10 and 1:25 to insure that the endotoxin concentration of the sample falls within the range of the standard curve. A 0.1 ml aliquot of diluted sample or reference endotoxin standard is added to a chilled test tube containing 1.0 ml LAL reagent. The contents of the tube are thoroughly but gently mixed, and the tube is put into a 37°C water bath to incubate for 60 ± 1 minutes. The contents of the tube are transferred to a cuvette, and the optical density measured with a Varian Techtron UV-Vis spectrometer. A five point standard curve is constructed using the concentration and optical density of the reference endotoxin standards. The optical density of each sample is compared to the standard curve to determine concentration of endotoxin in the sample.

Quality Control—

Sterility of medium, dilution water, glassware, and membrane filters is verified by preparing blank control plates with each set of samples examined by the standard plate count or total coliform procedures. Standard plate counts are plated in duplicate. Precision data for standard plate counts are presented in the supplementary data, Table S14.

SECTION 5

RESULTS AND DISCUSSION

GENERAL OBSERVATIONS

The experimental program was designed to simulate the variable stress conditions the units might experience in home use. Tap water, drawn from the municipal water supply, was employed as the basic inlet water. The Mississippi River is the raw water source. Classical treatments of permanganate oxidation as needed, flocculation, lime softening and disinfection at the water treatment plant are employed. Typical properties of the tap water are shown in Table 1.

Gulf South Research Institute is approximately 10 miles from the treatment plant. The Institute's water is obtained through a feeder line that connects approximately 1 mile from the site with one of the distribution loops of the city. Sharing the feeder line with GSRI are three light industries, one recreational park and three military reserve centers. The average water consumption in the laboratory while the tests were conducted was 153,000 gallons per month. The monthly average for the previous six months was 269,300 gallons. While usage was down during the test period the volume of water flowing through the building was adequate to maintain a representative sample. It is estimated that the water at GSRI point of use has had approximately 48 hours residence in the distribution system.

There are several features of this tap water that may distinguish it from some other sources. The pH of the water is basic; normal values are between 9 and 10. Total nonpurgeable organic carbon concentrations are not exceptionally high; however, the mixture of organic compounds that comprise this total may be one of the most complex groups of chemicals found in drinking water supplies. The Mississippi River contains pollutants from all surface waters drained from the mid-continental United States. This

TABLE 1. CHEMICAL CHARACTERIZATION OF AMBIENT NEW ORLEANS TEST WATER, JULY 1978

Constituent	Sample Concentration	Method Detection Limit	Method of Determination
arsenic	ND*	5 µg/l	FAAS*
barium	100 µg/l	30 µg/l	FAAS
cadmium	ND	1 µg/l	FAAS
chromium	ND	5 µg/l	FAAS
lead	ND	5 µg/l	FAAS
mercury	ND	0.2 µg/l	FAAS
selenium	ND	5 µg/l	FAAS
silver	ND	1 µg/l	FAAS
fluoride	1.2 mg/l	0.1 mg/l	specific ion electrode
nitrate-N	0.9 mg/l	0.05 mg/l	cadmium reduction
conductivity	350 µmhos/cm	—	conductivity meter
pH	9.5	—	pH meter
total dissolved solids	255 mg/l	—	gravimetric
turbidity	0.02 NTU	—	nephelometer
lindane	ND	0.004 µg/l	EC-GC*
heptachlor	ND	0.001 µg/l	EC-GC
aldrin	ND	0.001 µg/l	EC-GC
heptachlor epoxide	ND	0.002 µg/l	EC-GC
DDE	ND	0.003 µg/l	EC-GC
DDD	ND	0.003 µg/l	EC-GC
DDT	ND	0.009 µg/l	EC-GC
dieldrin	ND	0.002 µg/l	EC-GC
endrin	ND	0.003 µg/l	EC-GC
toxaphene	ND	0.061 µg/l	EC-GC
methoxychlor	ND	0.009 µg/l	EC-GC
2,4-D	ND	0.023 µg/l	EC-GC
2,4,5-T	ND	0.011 µg/l	EC-GC
Silvex	ND	0.016 µg/l	EC-GC

*ND - not detected
FAAS - flameless atomic absorption spectrophotometry
EC-GC - electron capture gas chromatography

water may contain humic, agricultural and other wastes; several cities dispose their sewage waste through the Mississippi River; the river has a large number of chemical and petrochemical industries along its banks, and the river is the backbone of the shipping industry for much of the country.

Parameters that might contribute to a better understanding of test results were monitored daily. These data are reported in "Phase 1 Supplemental Data," Figures S1 and S2. The room temperature fluctuated around 24°C. Larger variations are found in the fall and winter months when weather is unpredictable. GSRI practices energy conservation, with the heating and cooling system controlled by a 24-hour clock. While the building is not in use, the conditioning system is turned off. Many home users are currently exercising this same conservation practice and thus this pattern of use is consistent with home exposure. In the hot summer months a rise in room temperature of approximately 5°C was experienced in the off cycle period; this pattern moderated to a lowering of 2-3°C in winter months.

The average water temperature was approximately 2°C higher than room temperature in the summer, and dropping to around 6°C lower in the winter. These changes in temperature may influence trihalomethane influent concentrations, influent bacterial water quality, and possibly, free chlorine concentration but other circumstances may predominate for only one parameter, such as chlorine residual for bacterial quality.

The time history for influent bacterial and free chlorine properties of the test water are shown in Figure 4. Time history influent endotoxin data are reported in the supplementary data, Figure S3. Standard plate count and endotoxin data were obtained on samples that had remained stagnant for 8 hours in a test loop in the laboratory. Free chlorine data are from a runing water sample obtained in the middle of a sample day. No free chlorine was observed in the early stages, and accompaning high bacterial results were obtained. Beginning in September, free chlorine was consistently found in the running water samples. Standard plate counts and endotoxin concentrations decreased with the increase in free chlorine. These same parameters appear to be reduced further as the average water temperature dropped through the winter months.

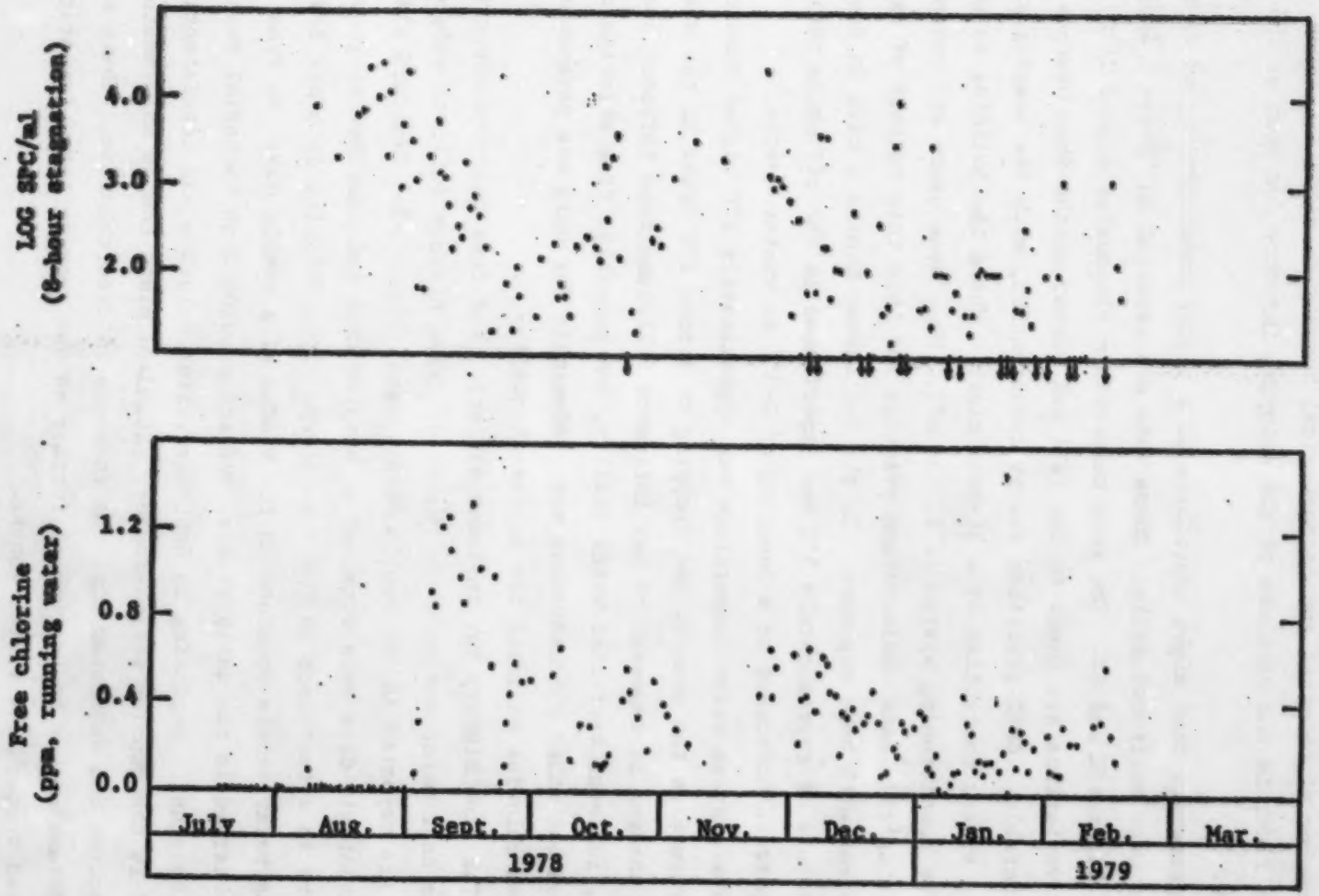

Figure 4. Influent plate count and free chlorine concentrations.

REMOVAL OF ORGANIC CONTAMINANTS BY HOME TREATMENT UNITS USING ACTIVATED CARBON

The proposed regulations for control of organic chemical contaminants in drinking water (18) propose a MCL of 0.1 mg/l for trihalomethanes and suggest use of activated carbon or equivalent treatment for removal of synthetic organic chemicals for systems determined to be vulnerable to such contamination. Activated carbon has been shown to have various levels of effectiveness in 1. removing organic compounds that produce taste and odor; 2. reducing disinfectant byproducts, and 3. removing or reducing concentrations of many synthetic organic chemicals.

Activated carbon is produced from several sources. Properties of the carbon are dependent on the method of preparation; surface area is the most important physical property of activated carbon. For specific application, the surface area available for adsorption depends upon the molecular size of the adsorbate and the pore diameter of the activated carbon. The rate of removal is related to the surface area and to diffusion in the liquid phase. Adsorption of an organic chemical on the activated carbon is dependent on a variety of factors including the polarity, molecular size, water solubility, and concentration of the compound in the water.

Trihalomethane Removal

The preceding discussion indicates that trihalomethanes may be removed from water by activated carbon. Seven units containing carbon have been evaluated. A physical description of the units is contained in Table 2. Adsorption capacity, as indicated by iodine number is reported in the supplemental data, Table S15. The amount of carbon in the units vary from 16 to 1120 g. Capacity ratings by the manufacturers, which should be dependent on amount and type of carbon, range from 200 gallons to an estimated 3420 gallons. All units tested have very short bed contact times; the longest is 46 seconds. This bed contact time is to be compared with 5-30 minute contact times used in water treatment plants (1). Tests conducted between July and November 1 employed tap water with THM concentration ranging from 151-304 ppb. In the second part of Phase 1, November 2 through February,

TABLE 2. PHYSICAL DESCRIPTION OF STUDY CARBON MODELS

Test Model	Type	Rated Capacity Liters (gallons)	Approximate Volume of carbon (cm^3)	Carbon Weight (grams)	Test flow rate liter/minute (gal/min)	Estimated Contact Time (sec)
Instapure	Faucet/bypass	757 (200)	50	27	1.9 (0.5) 5.7 (1.5)	1.6* 0.5**
Mini Aqua	Faucet/no-bypass	757 (200)	30	16	1.9 (0.5)	0.9
Aqualux	Line bypass	7570 (2000)	880	575	2.3 (0.6)	23
Everpure***	Line bypass	3875 (1000)	1650	765	2.3 (0.6)	43
System 1	Line bypass	9463 (2500)	1750	1120	2.3 (0.6)	46
Sears	Stationary	12945 (3420)	660	398	8.7 (2.3)	4.5
H_2OK	Pour-through	7570 (2000)	190	94	0.8 (0.2)	15

*Non-spiked water runs (using manufacturer's recommended flow rate)
**Spiked water runs (using experimentally determined flow rate)
***Figures represent totals for the two cartridge Everpure system.

the tap water was spiked with approximately 200 ppb chloroform. The spiking runs included a wide range of THM influent concentrations varying from 171 to 674 ppb. The increasing variability with spiking occurred because of the difficulty in obtaining a uniform spiked sample and to a higher variability of tap water as the water temperature changed with time.

The summary performance of the units is reported in Table 3. These data indicate that all of the stationary and line bypass units can measurably reduce trihalomethane concentrations. One unit removed approximately 93 percent of the THM challenge, with the other three units removing 43 to 46 percent of the challenge over the rated life of the units.

The units containing small amounts of carbon have limited capacity for THMs. The removal efficiency is also related to the short bed contact time, 1 to 15 seconds. While exhibiting reduced performance, two of these units removed 19 to 25 percent of the inlet load.

A summary plot of percent removal versus water processed is shown in Figure 5. One unit was designed specifically to remove THMs and was more than 90 percent effective over its rated life of 1000 gallons. This unit has a very large surface area available through the use of two cartridges, a granular and a powdered carbon filter. The carbon in one of the cartridges has a high iodine number, indicating good capacity, and the total bed contact time of 43 seconds is longer than that for most units. Claims for the other units vary from general removal of organics to removal of taste and odor components only.

In general, chloroform was the predominant THM; brominated THMs were adsorbed more readily on the activated carbon than chloroform; and removal efficiencies were almost identical for both the spiked and unspiked tests. One unit provided almost identical removal efficiences for THM and NPTOC when operated at a higher flow rate for the spiked run as compared to the unspiked run.

Approximately 5 percent of the data points deviated significantly from the general population, in some cases yielding apparent negative values. These data, in our opinion, are probably valid and may relate to specific, nonroutine stressing in the test program. The original data are reported

TABLE 3. SUMMARY PERFORMANCE-TRIHALOMETHANE REMOVAL DURING RATED LIFETIME

Unit	Type	Rated Gallonage	Average Influent Concentration (ppb)	Total Influent Load (g)	Amount Removed by Activated Carbon (g)	(%)
Instapure	Faucet/bypass					
	1. Spiked inlet	200	259.6	0.195	0.048	25
	2. Tap water	200	212.6	0.161	0.039	24
Mini Aqua	Faucet/no-bypass					
	2. Tap water	200	212.6	0.161	0.009	6
Aqualux	Line bypass					
	1. Spiked inlet	2000	348.0	2.634	1.175	45
	2. Tap water	2000	223.4	1.691	0.754	45
Everpure	Line bypass					
	1. Spiked inlet	1000	344.6	1.260	1.183	93
System 1	Line bypass					
	1. Spiked inlet	2500	346.8	3.258	1.396	43
	2. Tap water	2500	231.9	2.179	0.932	43
Sears	Stationary					
	1. Spiked inlet	3420	368.3	4.769	2.180	46
	2. Tap water	3420	229.2	2.967	1.357	46
H_2OK	Portable, pour-through					
	1. Spiked inlet	2000	353.6	2.677	0.514	19
	2. Tap water	2000	234.2	1.773	0.340	19

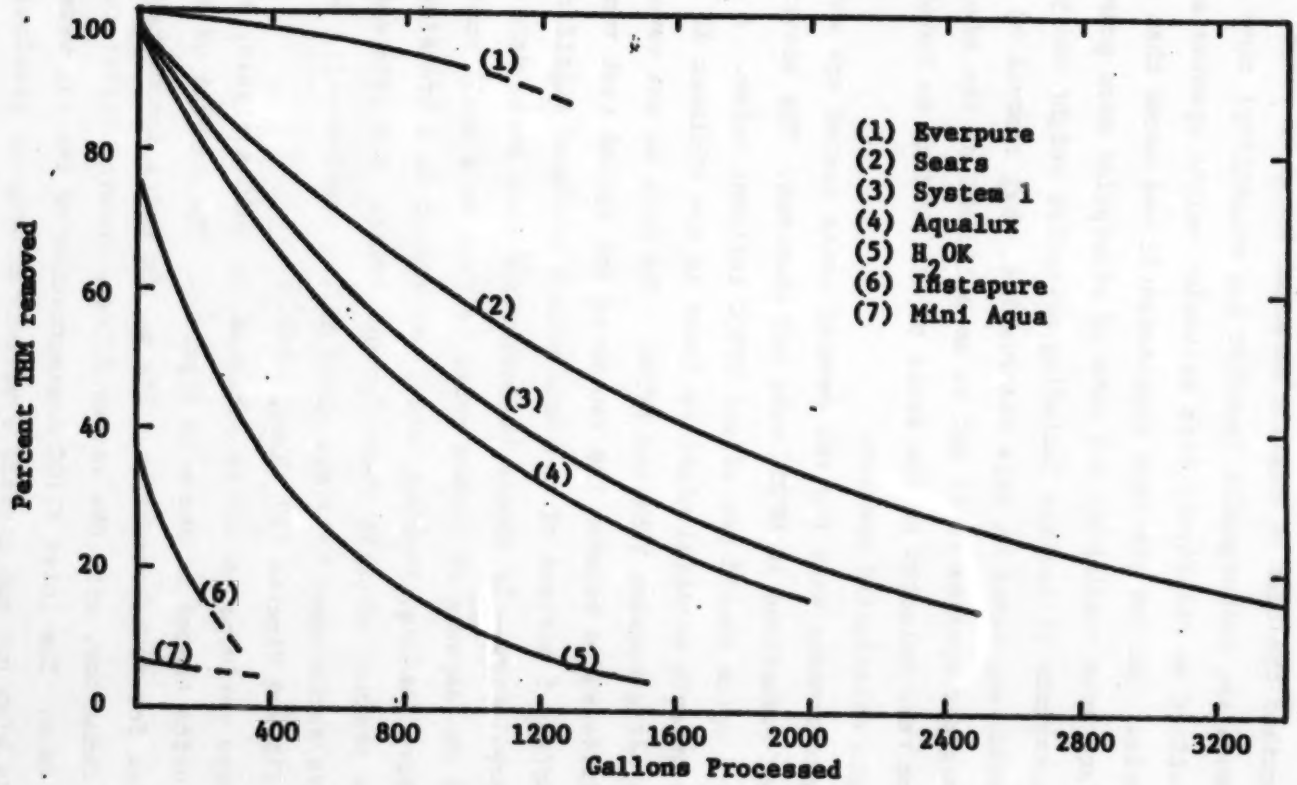

Figure 5. Summary performance of carbon units for THM removal.

in Tables S16 through S28 and Figures S4 through S19 of "Phase 1 Supplemental Data."

Nonpurgeable Total Organic Carbon

NPTOC describes the bulk of organic material found in water. Since these constituents are nonpurgeable (exhibit low volatility) they can be generally classified as relatively high molecular weight species and/or more polar species. In the previous discussion it was noted that the capacity (surface area available) and rate of adsorption were generally dependent on a variety of factors including molecular weight and polarity. It would be predicted, based on this observation, that removal of these nonpurgeable organic species would not be as efficient as the adsorption of THMs, if carbon were selected on the basis of its ability to reduce low molecular weight chlorinated species.

Summary performance data for the several units tested are shown in Table 4. Major reductions in NPTOC were not observed. The addition of chloroform as a spike should not affect NPTOC influent value. A smaller amount of the organic material might be found in the effluent if there were competitive binding between THMs and NPTOC. The data do not reveal any significant differences between the tap water and spiked test runs.

Approximately 5 percent of the data points deviated significantly from the general population. It should be emphasized that these data are probably valid; one of the aspects of carbon units is that in a small number of cases, premature loading, fouling, etc., may result in a transfer of collected matter to the product water in these "spent" units. Raw data and additional representative performance data are shown in the supplementary data, Tables S16 through S28 and Figures S20 through S23.

An average performance can be obtained for this analysis, and a summary plot of the units tested is shown in Figure 6. The removal of NPTOC was less than that for trihalomethanes. Six of the units demonstrated a measureable reduction, with the larger filters showing higher removals than the smaller ones. The inlet NPTOC concentration of the tap water was not exceptionally high but may contain a variety of organic chemicals.

TABLE 4. SUMMARY PERFORMANCE-NONPURGEABLE TOTAL ORGANIC CARBON REMOVAL DURING RATED LIFETIME

Unit	Type	Rated Gallonage	Average Influent Concentration (ppm)	Total Influent Load (g)	Amount Removed by Activated Carbon (g)	Amount Removed by Activated Carbon (%)
Instapure	Line bypass					
	1. Spiked inlet	200	2.642	2.000	0.228	11
	2. Tap water	200	2.193	1.660	0.189	11
Mini Aqua	Faucet/no-bypass					
	2. Tap water	200	2.193	1.660	0.026	2
Aqualux	Line bypass					
	1. Spiked inlet	2000	2.664	20.166	5.606	28
	2. Tap water	2000	2.252	17.040	4.741	28
Everpure	Line bypass					
	1. Spiked inlet	1000	2.573	9.739	3.955	41
System 1	Line bypass					
	1. Spiked inlet	2500	2.630	24.886	4.871	20
	2. Tap water	2500	2.244	21.233	4.156	20
Sears	Stationary					
	1. Spiked inlet	3420	2.682	34.718	4.011	12
	2. Tap water	3420	2.164	28.012	3.237	12
H_2OK	Portable, pour-through					
	1. Spiked inlet	2000	2.595	19.644	1.977	10
	2. Tap water	2000	2.522	19.092	1.922	10

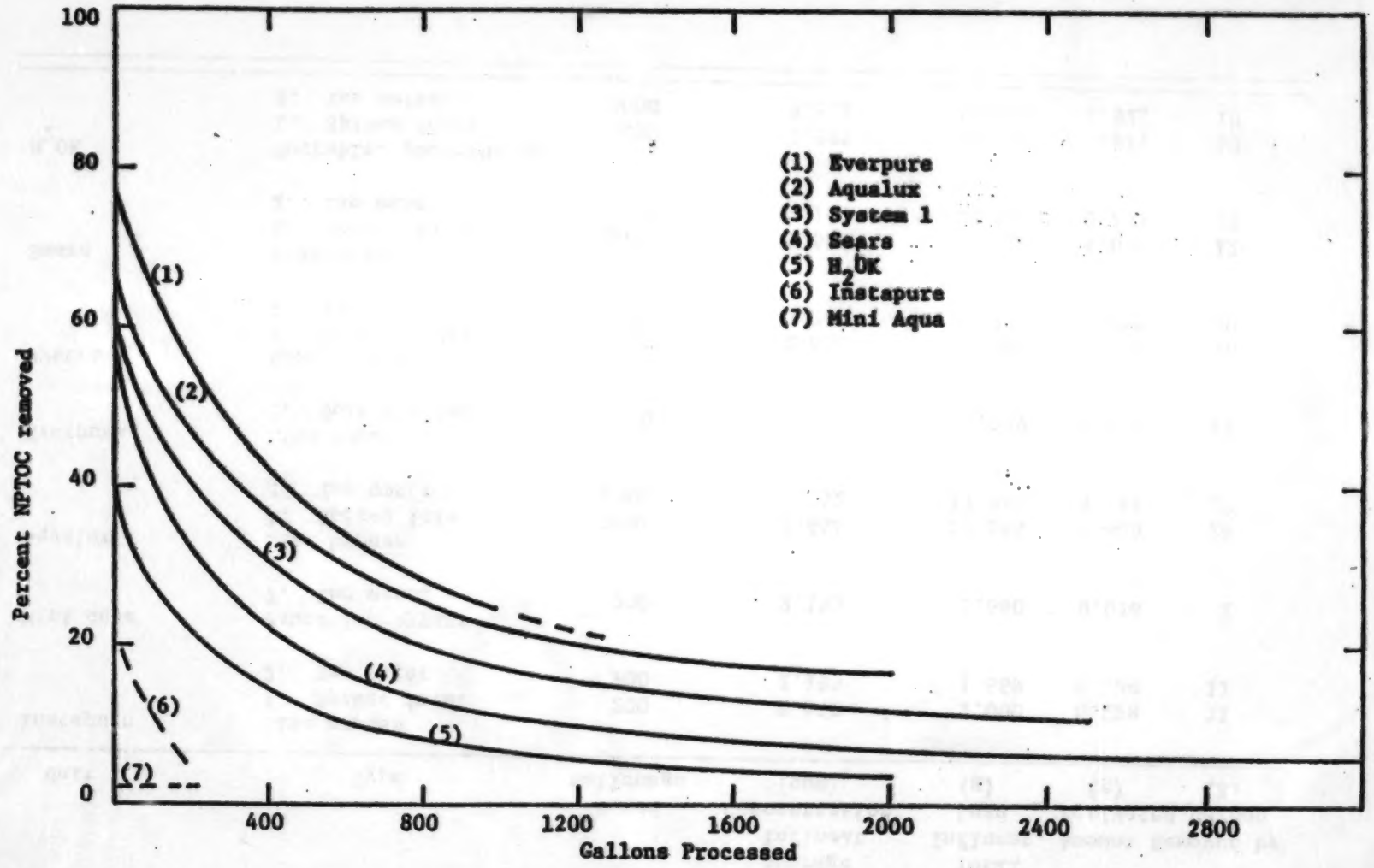

Figure 6. Summary performance of carbon units for NPTOC removal.

Nonpurgeable Total Organic Halogen

Many organic contaminants in a water stream may undergo reaction during chlorination. In addition, chlorinated materials are present in raw water sources. These range from chlorinated solvents from industrial sources to pesticides and herbicides from agriculture runoff. Activated carbon has been used in water treatment plants to reduce the level of these materials. A limited evaluation (three data points per unit) was performed on the seven units. The data are summarized in Table 5. Analyses for NPTOHa were conducted by the Kuhn-Dressman technique. Initial reductions were observed for all but two units. However, the results varied widely, including a number of negative percent removals, so that average removals could not be computed for most units. One unit with consistent results averaged 79 percent removal. Test data are reported in Table S29 of the supplementary data report.

Gas Chromatography/Mass Spectrometry Results

Six samples were analyzed for purgeable and semivolatile organic compounds using GC/MS. These samples included an effluent from each of five different units and one influent. All samples were collected at approximately the same time using the protocol specified for THM samples. Trihalomethane levels in two similar samples were determined by both GC/MS and gas chromatography using an electron capture detector (GC/EC). Concentrations were within the same order of magnitude. In general, both the GC/EC and GC/MS analysis data were completely compatible. THMs were the only compounds identified in drinking water above the 0.1 ng/ml level (0.1 to 190 ng/ml).

The semivolatile analysis of 4 liters of drinking water by GC/MS did not detect any organic compounds above 1 ng/ml. These results indicate that some preconcentration procedures are needed to detect organic compounds in drinking water at or below the 1.0 ng/ml level.

TABLE 5. SUMMARY PERFORMANCE OF ACTIVATED CARBON UNITS FOR REMOVAL OF NONPURGEABLE TOTAL ORGANIC HALIDES

Model	Average Inlet Concentration of NPTOHa (ppb)	Rated Usage (gallons)	Average Initial Percent Removed	Average % Removed Over Rated Life
Instapure	94	200	-(25)	*
Mini Aqua	104	200	-(92)	*
Aqualux	97	2000	68	*
Everpure	100	1000	98	79
System 1	87	2500	57	*
Sears	93	3420	57	*
H_2OK	113	2000	56	*

*NPTOHa results varied widely, including a number of negative values for percent removal; therefore, average removal could not be computed for these units.

Bacteriological Results

Uncontrolled bacterial growth and accompanying by-product release have been major concerns associated with the use of home water treatment units based on sorption by activated carbon. While numerous reports have discussed the problem, the conclusions have varied widely. For example, Fiore and Babineau (7) summarized their findings that both filtered and unfiltered water responded to the same extent when left standing overnight. In addition, they report that activated carbon in the treatment of well water presented no additional biological problems. By contrast, Wallis, et al. (2) report substantial growth rates of bacteria supported on activated carbon; they attribute the growth to the localization of both seed bacteria and nutrients in the carbon particle. This could result in marked bacterial growth during quiescent overnight periods, with large bacterial counts resulting in the first effluent samples.

Johnston and Burt (3) sought to verify the Wallis conclusion and determine the fate of pathogenic bacteria using the coliform strain for their tests. Their results indicated that pathogenic bacteria as represented by the coliform group do not flourish in the filter environment. They conclude, "Bacteria indigenous to tap water are able to multiply quite well on compounds concentrated from tap water by charcoal filters; however, other types of bacteria such as coliform bacteria may not fare as well."

This information suggests that bacteria may multiply under conditions found in a home water treatment unit attached to a drinking water tap. There are numerous parameters that may minimize this growth; e.g., free chlorine levels, running water, impregnation of the carbon with silver and temperature. Even the type of material adsorbed on the carbon could influence this growth.

The standard plate count procedure provides a means of assessing the number of aerobic and facultative anaerobic heterotrophic bacteria in water. This is an empirical determination because no one set of nutritive, chemical, and physical conditions can satisfy the requirements of all bacteria in a water sample. It should be pointed out that some bacteria are nearly always present in drinking water and are considered to be nonpathogenic under normal home-use situations. However, the concern has been expressed that high exposure to some normally nonpathogenic organisms can result in

risk to some persons. The coliform group of bacteria were not an object of this study although some coliform measurements were taken to provide background data.

Summary influent and effluent SPC results are presented in Table 6. Influent SPC and free chlorine concentrations are shown in Figure 4; SPC populations appeared to fall as free chlorine concentrations rose, and showed great variability. The SPC results were segregated into three sets: 1) effluent levels at least one log (1/10) below influent levels; 2) effluent levels at least one log (10 times) higher than influent levels; and 3) effluent levels within $\pm$ one log of the influent levels. These breakdowns were necessary since bacteria are subject to rapid change and variability so that significance needs to be interpreted in terms of log changes rather than arithmetically.

Reviewing the data in Table 6, it may be noted that all units had data sets where effluent exceeded influent by one or more log ranging from 15 to 59 percent. The incidence of effluent levels one log or more below influent levels was much lower than for exceeders, with a range of zero for four units to 18 percent for one unit. The majority of units had the largest portion of data sets in category 3: five of seven units had effluent levels within one log of influent levels with the range from 41 to 83 percent. The pattern of results for individual units could be quite variable, with reversals occurring between one test point and the next in the same run. These preliminary data showed moderate and variable effects of activated carbon on bacterial levels in effluent waters as compared with tap water sampled under comparable conditions.

TABLE 6. SUMMARY OF STANDARD PLATE COUNT DATA

	Instapure*	Mini Aqua*	Sears*	H_2OK**	System 1**	Aqualux Water**	Everpure*
Total number and (percent) of comparable data sets	28(100)	6(100)	30(100)	26(100)	33(100)	31(100)	22(100)
Number and (percent) of data sets with the effluent one log or more below the influent values	0(0)	0(0)	5(17)	2(8)	6(18)	0(0)	0(0)
Number and (percent) of data sets with effluent exceeding influent values by one log or more	15(54)	1(17)	10(33)	6(23)	5(15)	14(45)	13(59)
Number and (percent) of data sets with effluent plate counts within ± one log of the influent value	13(46)	5(83)	15(50)	18(69)	22(67)	17(55)	9(41)
Average effluent silver concentration for all test runs	Not run	Not run	Not run	5 µg/l	4 µg/l	4 µg/l	Not run
Range of SPC/ml							
Influent	9-24000	6600-24000	0-39000	<10-22000	0-39000	<10-11000	5-15000
Effluent	5-190000	160-120000	<10-320000	0-240000	30-20000	<10-120000	<100-130000

*Does not contain silver; no silver analysis performed.
**Contains silver-impregnated carbon and was analyzed for silver.

Under test conditions with tap water, these preliminary results may show a limited effect on bacterial populations for silver as against non-silver units but not to the extent of being consistently bacteriostatic. Factors other than silver may affect bacterial growth such as flow rate, flow patterns, carbon characteristics and design factors. Stress conditions such as temperature and chlorine concentration will also affect bacterial levels.

Endotoxins are derived from the cell walls of dead bacteria (the gram-negative bacteria which comprise a major part of the SPC population) and thus represent a comparable measure of biological activity in the drinking water. When injected into the blood stream of animals or humans, endotoxins can cause the elevation of body temperatures, known as pyrogenic activity. However, the levels of endotoxins in water are relatively quite low and are introduced to the gastrointestinal tract rather than directly into the blood. In one study (4), the injection of drinking waters of varying endotoxin content (1.2-25 ng/ml) from 27 different water supplies utilizing activated carbon treatment failed to demonstrate pyrogenic activity in any of 28 rabbits tested. While the presence of endotoxins is not presently known to be a hazard in drinking water, their measurement is still of interest, as representing bacterial activity.

Summary influent and effluent endotoxin results are presented in Table 7. While SPC ranged over 6 orders of magnitude, endotoxin concentrations were all within one order of magnitude. The endotoxin results were segregated into three sets: 1) effluent levels one half or less than influent levels; 2) effluent levels twice or more than influent levels; and 3) effluent levels between one-half and twice influent levels. Reviewing the data in Table 7, it may be noted that all of the units had more data sets in the exceeding category than in the reduced category; however, the roughly equal category contained 50 percent or more data sets for all units. These preliminary data would seem to indicate that while activated carbon served to increase endotoxin levels, there were reversals and that the overall effect should be considered minimal. One factor limiting the increase of endotoxins might be the ability of the carbon to adsorb the endotoxin material.

TABLE 7. SUMMARY OF ENDOTOXIN DATA

	Instapure	Mini Aqua	Sears	H_2OK	System 1	Aqualux	Everpure
Total number and (percent) of comparable data sets	29(100)	6(100)	32(100)	33(100)	29(100)	28(100)	19(100)
Number (percent) of comparable data sets with effluent endotoxin values less than one-half the influent value	3(10)	0(0)	2(6)	0(0)	1(3)	1(4)	0(0)
Number and (percent) of data sets with effluent exceeding influent values by 2-fold	10(35)	2(33)	12(38)	11(33)	11(38)	13(46)	9(47)
Number and (percent) of data sets with effluent endotoxin between 0.5X and 2X the influent endotoxin value	16(55)	4(67)	18(56)	22(67)	17(59)	14(50)	10(53)
Range of endotoxin (ng/ml)							
Influent	0.2-9.0	0.3-9.0	0.9-7.5	0.5-4.0	0.9-7.5	0.3-5.5	0.4-4.0
Effluent	0.2-14.1	0.2-8.3	1.0-18.0	0.9-7.3	0.6-6.8	1.2-8.8	1.1-6.6

The range of endotoxin influent and effluent levels were unremarkable except for the 18.0 ng/ml non-silver effluent maximum, which happened to be coincident with the highest SPC concentration in this study (320000). The maximum endotoxin concentrations in this study are comparable with those reported by Wolf, et al. (4) for a selection of public water supplies. Data were too limited to make correlations between SPC and endotoxin levels. There was little if any difference between the pattern of endotoxin levels for silver-impregnated and non-silver units.

Standard plate count and endotoxin concentrations were determined on the used and unused carbons from all models. Bacteria were rinsed from the carbon samples into sterile, pyrogen-free water and water samples were analyzed. These tests showed negligible SPC and endotoxin levles in the unused filter material. SPC and endotoxin on the used carbon were measurable but not outstanding; influent side analyses for SPC were higher for some units than the effleunt side but this was not a consistent pattern. Finally, quantifications for coliform bacteria were all negative with the

exception of one result, which was not reproduced in any replicate models and was felt to be caused by extraneous contamination. All test data for the bacterial evaluations are contained in "Phase 1 Supplemental Data," Table S30 through S45 and Figures S24 through S83.

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